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ORIGINAL COMMUNICATION

Population-based incidence and 5-year survival for hospital-admitted traumatic brain and spinal cord injury, Western Australia, 2003–2008

Rachael Moorin · Ted R. Miller · Delia Hendrie

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Abstract This study aimed at analysing first-time hospitalisations for traumatic brain injury (TBI) and spinal cord injury (SCI) in Western Australia (WA), in terms of socio-demographic profile, cause of injury, relative risks and survival, using tabular and regression analyses of linked hospital discharge and mortality census files and comparing results with published standardised mortality rates (SMRs) for TBI. Participants were all 9,114 first hospital admissions for TBI or SCI from 7/2003 to 6/2008, linked to mortality census data through 12/2008, and the main outcome measures were number of cases by cause, SMRs in hospital and post-discharge by year through year 5. Road crashes accounted for 34 % of hospitalised TBI and 52 % of hospitalised SCI. 8,460 live TBI discharges experienced 580 deaths during 24,494 person-years of follow-up. The life-table expectation of deaths in the cohort was 164. Post-discharge SMRs were 7.66 in year 1, 3.86 in year 2 and averaged 2.31 in years 3 through 5. 317 live SCI discharges experienced 18 deaths during 929 years of follow-up. Post-discharge SMRs were 7.36 in year 1 and a fluctuating average of 2.13 in years 2 through 5. Use of data from model systems does not appear to yield biased SMRs. Similarly no systematic variation was observed between all-age studies and the more numerous studies that focused on those aged 14 to 16 and older. Based on two studies, SMRs for TBI, however, may be higher in year 2 post-discharge in Australia than elsewhere. That possibility and its cause warrant exploration. Expanding public TBI/SCI compensation in WA from road crash to all causes might triple TBI compensation and double SCI compensation.

Keywords TBI · SCI · Incidence · Standardised mortality rates · Compensation scheme

Introduction

As in other industrialised countries acute injury is the leading cause of morbidity and mortality in Australia accounting for 7 % of all hospital separations per year [11]. Injured persons have significantly more overall health service use than the general population and increased use of mental health services for both those with and without pre-injury mental health conditions [11]. Traumatic brain (TBI) and spinal cord injuries (SCI) are debilitating and have life-long impact upon injured people and their families. Apart from the physical impact of these injuries they also affect many aspects of daily living including ability to work and take part in social and community activities.

Brain injury can be devastating affecting cognition, emotion, behaviour and memory in addition to physical abilities [14]. TBI is characterised by an external assault on the head that results in damage to the brain, which may be in the form of a blow, blunt force or rapid forward and back motion experienced in rapid sudden deceleration. It is a non-degenerative, non-congenital insult to the brain from an external mechanical force possibly leading to permanent or temporary impairments of cognitive, physical and psychosocial functions [14]. Males are at higher risk of TBI than females with the highest risk to adolescent/young

R. Moorin · T. R. Miller (✉) · D. Hendrie
Centre for Population Health Research, Faculty of Health Sciences, Curtin University, Building 400, GPO Box U1987, Perth, WA 6845, Australia
e-mail: miller@pire.org

T. R. Miller
Pacific Institute for Research and Evaluation, 11720 Beltsville Drive, Suite 900, Calverton, MD 20705, USA

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adult males. Road crashes, falls and assaults are reported as the top three causes of injury with alcohol reported as an important factor [14]. In 2004 to 2005 TBI resulted in over 26,000 episodes of hospitalisation in Australia with an estimated direct cost of hospital care of A$184 million. Total estimated cost of TBI in Australia in 2008 was $8.6 billion with lifetime cost of A$2.5 million per moderate case and A$4.8 million per severe case [1].

Similarly, SCI can be a catastrophic injury. It often results in profound and long-term disability, which is life changing for the individual and family [23]. These injuries are associated with significant social, health care (treatment and rehabilitation) costs and productivity losses. SCI refers to an acute, traumatic lesion of neural elements in the spinal canal resulting in temporary or permanent sensory deficit, motor deficit or bladder/bowel dysfunction [1]. The leading causes of SCI in Australia are road crashes, falls and water-related incidents. The age-adjusted rate of persisting SCI is 14.5 per million (1998/1999). Young adults and males are most at risk [21]. In 2008 an estimated 2,766 new cases of SCI occurred in Australia of which 1,000 would be classified as severe [1]. Total estimated cost of SCI in Australia in 2008 was A$2 billion with estimated lifetime cost per incident case of A$5 million for paraplegia and A$9.5 million for quadriplegia [1].

Following injury, up to 70 % of individuals suffering TBI or SCI do not return to work, increasing community cost through unemployment and welfare payments [21]. Thus the increasing prevalence of these injuries signals the potential for escalating health and welfare costs.

In Australia a large proportion of cases do not receive insurance compensation for their injury with different jurisdictions having different compensation schemes. In Western Australia (WA) the Insurance Commission of Western Australia (ICWA) is the statutory authority established as the sole provider of motor vehicle third party (personal injury) insurance. The WA scheme is a common law, fault-based scheme where, for a claim to succeed, it is necessary that negligence be established against the owner or driver of a WA registered vehicle. Importantly this scheme does not cover the driver for injuries received as a result of his/her own negligence. Thus a significant proportion of injuries sustained resulting from road crashes in WA is non-compensable. The only other compensation scheme in WA covering injuries is the Workers Compensation Scheme which is limited to injuries sustained at work. Individuals with injuries not compensable under these two schemes receive no compensation.

The issue of a no-fault long-term care scheme for people catastrophically injured (TBI and SCI) in road crashes or otherwise has been on the national agenda in Australia for some years [22]. Since those who are not eligible for compensation have worse outcomes in addition to facing a more challenging future financially, some advocate for a more inclusive compensation scheme [22]. Some jurisdictions of Australia addressed this need by implementing no-fault compensation schemes, where all are covered (e.g., the Victorian Transport Accident Commission scheme, the New South Wales long term care scheme for all catastrophically injured individuals). Given the strength and performance of the WA road crash scheme and the desirable social aspects of a more comprehensive no-fault scheme, ICWA is discussing introducing one in WA.

Currently, accurate data are lacking in WA on the epidemiology of TBI and SCI resulting from causes other than road crashes. Those data can be helpful inputs in assessing the burden of SCI and TBI, as well as in prevention planning. They also are needed as a basis for decisions regarding viability of extensions to the current scheme. Specifically, data are needed on relative frequency of TBI and SCI from road crashes versus other causes and on survival post-discharge. These data will support estimation of the number of people who gain compensation in extending coverage from road crash to all injury and of differences in likely cost per case resulting from differential survival.

Availability of population-wide person-based record linkage in WA allows for complete, reliable whole of population epidemiological data about TBI and SCI requiring hospitalisation in the State. Thus the aim of this study was to evaluate the incidence of first-time hospitalisations for TBI and SCI, in terms of the socio-demographic profile, cause of injury, relative risks and survival. The study's post-acute survival rates are population-based which may make them more representative than many existing estimates, which come from specialty care centres.

Methods

Study design and data sources

This study used a population-based longitudinal methodology incorporating linking of routinely collected WA hospital morbidity data system (HMDS) and WA mortality register data. Following human research ethics approval, WA Data Linkage Unit (WADLU) staff linked these records at the individual level using a unique encrypted code [15]. All data were de-identified prior to release to the researchers for analysis with the extraction process following a privacy-protecting best practice protocol [16]. Records released covered all hospital admissions to Western Australian public and private hospitals occurring between 1st January 2002 and 30th June 2008 linked to mortality in WA with a date of death from 1st January 2003 to 31st October 2009.

Table 1 ICD-10-AM codes used in selection of traumatic head and spinal injury separations

Head injuries	Traumatic brain injury ICD-10 codes
Fracture of skull and facial bones	S02 (0.1, 0.3, 0.7, 0.8 and 0.9)
Intracranial injury	S06.0–S06.9
Crushing injury of head	S07.0–S07.9
Unspecified injuries of head	S09.7
Spinal injuries	**Spinal cord injury ICD-10 codes**
Injury of nerves and spinal cord of cervical region	S14.0; S14.1–S14.13; S14.70–S14.78
Injury of nerves and spinal cord of thoracic region	S24.0; S24.10–S24.12; S24.70–S24.77
Injury of nerves and spinal cord of lumbar region	S34.0; S34.70–S34.76

Case selection

This study defined a traumatic injury as a hospital inpatient admission with an external cause code of activity (U50-U73); unintentional (V01-W84) or assault (X85-Y09) on the HMDS records. (No suicide acts involving TBI or SCI appeared in the data set). Thus injuries resulting in death at the scene or death en-route to hospital were excluded as were injuries that did not require hospital admission (i.e., where the individual was treated in the emergency department and released or left against medical advice without admission as an in-patient). The study was restricted to first-time hospitalisations; subsequent hospitalisations for the same type of injury (TBI or SCI) were excluded from the analysis. TBI and SCI were evaluated separately so a single patient could appear in both analyses.

After restricting the HMDS data set to records having an external cause code indicating a traumatic event (as detailed above) the data were further restricted to those having diagnosis codes (principal diagnosis or co-diagnosis) of TBI or SCI. The ICD-10 diagnosis codes used to define TBI and SCI are shown in Table 1.

Data preparation

Once all episodes of hospitalisation were categorised, the first-time occurrence (based on the date of admission) was classified as the first-time event. Only first-time events occurring between 1st July 2003 and 30th June 2008 inclusive were used in this analysis. To remove any prevalent cases from the analysis, individuals with first-time hospitalisations occurring prior to 1st July 2003 were removed from the study. Individuals included in the analysis were assigned an age group on the basis of their age at first-time admission to hospital. These age groups were 0–4, 5–14, 15–24…70+ years. These age groups were further aggregated into broad age groups to improve cell counts for some analyses (e.g., 0–14 years).

Nature of injury

To gain insight into injury severity, the TBI analysis differentiated TBIs that included intracranial injury and ones that included skull fractures from ones that included neither. The SCI analysis differentiated cervical from thoracic/lumbar SCI.

Cause of injury

The external cause code recorded on the first-time hospitalisation was used to categorise the cause of injury category responsible for the hospitalisation using four broad categories: Road crash (V01-V99), Fall (W00-W19), Assault (X85-Y09) and Other cause (U50-U73 and W20-W84).

Socio-economic status

Health disparities potentially might affect survival of these catastrophic injuries. To test that possibility, the models analysed the effect of socio-economic status. Determination of socio-economic status used the residential address for each record as geocoded to Australian Bureau of Statistics (ABS) postal areas by the WADLU. Socioeconomic status was determined by mapping published quintiles of the Socio-Economic Index for Areas (SEIFA) index of relative social disadvantage (IRSD) scores to the postcodes of cases reported on the HMDS data [3].

Location of residency

In order to examine the geographical distribution of SCI and TBI cases across WA individuals were classified to a location using three broad categories: Metropolitan, Rural and Remote according to the postcode of residency recorded on the HMDS record. Outcomes and aetiology may differ by location due to exposure differences, longer emergency response times, or reduced health care access.

Survival

The mortality data were used to determine if the individual died during the study period. A created variable identified time from discharge to death.

Follow-up time

Follow-up time was calculated from the admission date of the first-time hospitalisation to date of death (regardless of cause) or end of study in days.

Calculation of person time at risk

Person time at risk used as the denominator in the rate calculations was constructed using either (a) the relevant gender- and age-specific ABS resident population of WA [2], or (b) the gender-specific count of individuals in each IRSD quintile using published ABS 2006 SEIFA population data for WA [3].

Data analysis

The number, proportion and rate (per 100,000 person years at risk) of first-time hospitalisations for both TBI and SCI were calculated according to gender, age and cause of injury.

Risk of injury-related death, conditional upon survival to first-time hospitalisation, was evaluated using multivariate Cox proportional hazards regression analysis and the same explanatory variables. Cox regression analyses survival whereby each person has a time zero (which for this study is date of first hospitalisation), then is followed until death OR censorship (no longer having the opportunity to have the event of interest) at the end of the study period. The method accounts for both the follow-up time and censoring. Standard mortality ratios (SMRs) were computed as mortality rates in the data divided by the life-table mortality rate for the age-sex cohort of the patients.

Case definition in this study is based on hospital administrative diagnosis coding from charts that was not verified by trauma specialists. Consequently, some unknown number of chronic subdural haematomas in older people as a result of minimal trauma were coded, perhaps inappropriately, as TBI. These cases could have high case fatality rates because elders with this condition tend to be frail. To check if these cases could distort the findings, we reran the regression omitting those over age 60 whose only TBI diagnosis was an intracranial injury with a cause-code in our Fall or our Other Cause category.

Results

As Table 2 shows, 8,779 first-time hospitalisations for TBI and 335 first-time hospitalisations for SCI occurred in WA between 1st July 2003 and 31st June 2008. The TBI incidence rate of 85.8 per 100,000 person years at risk was 26 times the SCI rate of 3.3 per 100,000. TBI was concentrated in four age groups (0–4, 5–14, 15–29 and 70+ years). Mean age was 28.2 years for TBI patients injured in road transport and 40.8 years for other TBI patients (not

Table 2 Number, proportion and rate of first-time traumatic brain and spinal cord injury hospitalisations in Western Australia by gender and age, July 2003 to June 2008

Age group	Traumatic brain injury					Traumatic spinal cord injury				
	n	%	Rate/ 100,000	95 % CI		*n*	%	Rate/ 100,000	95 % CI	
				Lower	Upper				Lower	Upper
Male										
0–4	369	6.2	109.8	72.2	147.5	2	0.8	0.6	0.0	3.4
5–14	1,024	17.3	142.2	79.4	204.9	6	2.4	0.8	0.0	5.6
15–29	1,891	32.0	169.6	84.4	254.9	88	35.2	7.9	0.0	26.3
30–49	1,165	19.7	76.0	9.1	142.9	75	30.0	4.9	0.0	21.9
50–69	717	12.1	65.8	13.3	118.2	52	20.8	4.8	0.0	18.9
70+	745	12.6	204.3	150.8	257.8	27	10.8	7.4	0.0	17.6
Female										
0–4	314	10.9	99.0	64.2	133.7	1	1.2	0.3	0.0	2.3
5–14	381	13.3	56.5	18.2	94.7	5	5.9	0.7	0.0	5.1
15–29	563	19.6	53.7	7.2	100.2	24	28.2	2.3	0.0	11.9
30–49	434	15.1	28.7	0.0	69.6	18	21.2	1.2	0.0	9.5
50–69	367	12.8	34.6	0.0	72.2	19	22.4	1.8	0.0	10.3
70+	809	28.2	173.6	117.9	229.4	18	21.2	3.9	0.0	12.2
Total male	5,911	67.3	114.6	0.0	265.3	250	74.6	4.8	0.0	35.8
Total female	2,868	32.7	56.5	0.0	161.5	85	25.4	1.7	0.0	19.7
Total	8,779	54.5	85.8	0.0	269.4	335	5.1	3.3	0.0	39.1

Table 3 Number, proportion and rate of first-time traumatic head and spinal injury hospitalisations in Western Australia by cause of injury and age group, July 2003 to June 2008

Age group	Mechanism of injury											
	Road crash			Fall			Other			Assault		
	n	%	Rate/100,000	*n*	%	Rate/100,000	*n*	%	Rate/100,000	*n*	%	Rate/100,000
Traumatic brain injury												
0–14 years	630	30.2	30.8	1,059	50.7	51.7	394	18.9	19.2	5	0.2	0.2
15–24 years	1,066	55.1	72.5	386	20.0	26.3	432	22.3	29.4	50	2.6	3.4
25–44 years	806	45.7	27.1	499	28.3	16.8	386	21.9	13.0	74	4.2	2.5
45–64 years	345	28.8	13.6	636	53.0	25.0	193	16.1	7.6	25	2.1	1.0
65+ years	174	9.7	14.5	1,442	80.4	120.5	176	9.8	14.7	*	*	*
Total	3,021	34.4	29.5	4,022	45.8	39.3	1,581	18.0	15.4	155	1.8	1.5
Spinal cord injury												
0–14 years	7	50.0	0.3	5	35.7	0.2	*	*	*	*	*	*
15–24 years	49	62.0	3.3	14	17.7	1.0	15	19.0	1.0	*	*	*
25–44 years	73	67.6	2.5	16	14.8	0.5	17	15.7	0.6	*	*	*
45–64 years	27	35.1	1.1	28	36.4	1.1	21	27.3	0.8	*	*	*
65+ years	19	33.3	1.6	29	50.9	2.4	9	15.8	0.8	*	*	*
Total	175	52.2	1.7	92	27.5	0.9	64	19.1	0.6	*	*	*

* Cell contains less than 5 cases

tabulated). SCI was quite rare before age 15. It was most common among those of age 70+ and males of ages 15–29. Mean ages were 36.8 years for SCI patients injured in road transport versus 47.1 years for other SCI patients. Males accounted for 67 % of TBI and 75 % of SCI cases. Male TBI and SCI rates exceeded female rates in all age groups.

In terms of severity (data not tabulated), 23 % of TBI involved skull fractures and 88 % involved intracranial injury with no significant difference between rates in road crashes versus other causes. Similarly, 61 % of SCI were cervical with no significant difference between the 57 % rate for SCI in road crashes and the 64 % rate for all other SCI.

Table 3 shows the number, percentage and rate of events for each injury cause by age group. Falls accounted for the highest rate of TBI events (39 per 100,000 person years at risk) with the rate for road crashes (30 per 100,000 person years at risk) and other causes (15 per 100,000 person years at risk) much lower. Of 8,779 cases, 34 % (3,021) occurred in road crashes. In contrast, road crashes accounted for 52 % of all SCI cases (175/335). In both injury types assault accounted for the lowest rate of events.

Evaluating rates by age, those aged 15 to 24 years had by far the highest rates for both TBI and SCI in road transport crashes (72 and 3 per 100,000 person years, respectively). This age group also accounted for the highest rates of fall-related cases (120 and 2 per 100,000 person years for TBI and SCI, respectively).

Risk of death resulting from TBI or SCI conditional upon survival to inpatient hospitalisation

Table 4 shows survival data for the TBI and SCI cohorts. The large majority of deaths occurred in hospital. The death rates shown by time period are based on patients observed during that time period. For example, only those injured in Financial year 2003–2004 had survival data for the fifth year post injury. Overall, more than 13 % of both TBI and SCI admissions died within 5 years of injury.

In these census data, during 24,494 years of follow-up on the 8,460 live discharges from first TBI hospitalisation, 580 died. The life-table expectation of deaths in the cohort was 127 (0.52 % per year). The excess death rate was 7.0 % over 5 years. Post-discharge SMRs were 7.66 in year 1, 3.86 in year 2 and a fluctuating average of 2.31 in years 3 through 5. By the second year for SCI and the third year for TBI, excess mortality stabilised at roughly 0.5 % per year, which meant these patients had SMRs of 2.7 relative to their age-sex cohort.

During 929 years of follow-up on the 317 live discharges from first SCI hospitalisation, 18 died. The life-table expectation of deaths in the cohort was 5. The excess death rate was 5.7 %. Post-discharge SMRs were 7.36 in year 1 and a fluctuating average of 2.13 in years 2 through 5. SCI SMRs are based on small numbers of deaths and may not be stable.

Patient socio-economic status had no significant effect on survival for hospitalised TBI and SCI inpatients

Table 4 Deaths and probability of dying from traumatic brain or spinal cord injury by time since first hospitalisation in Western Australia, July 2003 to June 2008

Financial year	2003/4	2004/5	2005/6	2006/7	2007/8	Total	Death rate
(i) Traumatic brain injury							
First hospitalisations	1,776	1,779	1,752	1,717	1,755	8,779	
Died in hospital	65	57	70	72	55	319	0.0363
Died 1–30 days post-discharge	17	13	26	18	23	97	0.0115
Died 31–90 days post-discharge	8	24	11	12	14	69	0.0083
Died 91–364 days post-discharge	35	33	41	44	14	167	0.0201
Subtotal 1–365 days post-discharge	60	70	78	74	51	333	0.0399
Died 365–729 days post-discharge	39	39	27	25	0	130	0.0201
Died 730–1,094 days post-discharge	25	28	12	0	0	65	0.0135
Died 1,095–1,460 days post-discharge	25	8	0	0	0	33	0.0104
Died 1,461–1,825 days post-discharge	19	0	0	0	0	19	0.0122
Total deaths	233	202	187	171	106	899	0.1324[a]
(ii) Spinal cord injury							
First Hospitalisations	67	73	58	75	62	335	
Died in hospital	4	4	3	4	3	18	0.0537
Died 1–30 days post-discharge	2	1	2	1	1	7	0.0221
Died 31–90 days post-discharge	0	1	0	0	2	3	0.0097
Died 91–364 days post-discharge	0	1	0	1	0	2	0.0065
Subtotal 1–365 days post-discharge	2	3	2	2	3	12	0.0383
Died 365–729 days post-discharge	0	2	0	0	0	2	0.0080
Died 730–1,094 days post-discharge	2	0	0	0	0	2	0.0112
Died 1,095–1,460 days post-discharge	0	1	0	0	0	1	0.0081
Died 1,461–1,825 days post-discharge	1	0	0	0	0	1	0.0169
Total deaths	9	10	5	6	6	36	0.1364[a]

[a] Total death rate is for patients with 5 years of post-discharge exposure

(Table 5). For TBI, risk of death was modestly higher for patients with skull fractures or intracranial injuries. It rose steadily and sharply with age. Rural residents had elevated TBI death rates. Death rates also were significantly higher for TBI resulting from fall or assault than from road crash or other cause. For hospitalised SCI, the elderly and possibly children under age 15 were at elevated risk of death compared to patients aged 15 to 64. Controlling for age, SCI mortality did not differ by gender or cause.

In sensitivity analysis, dropping 1,295 elderly patients with isolated intracranial injuries, most of them due to falls, created some artificial multicollinearity between the 0–1 indicator variables for fracture, elderly and fall (e.g., having a fracture made it more likely the patient was elderly and had fallen). That caused regression coefficients to change for those variables (table not shown). It negligibly impacted the coefficients on other significant explanators in the model. The odds ratio on elderly fell to 49:1, high enough to make it clear that including some chronic cases among the many isolated subdural haematomas of the elderly is not distorting the mortality rate.

Discussion

Western Australian data echo Australia-wide findings that male TBI and SCI rates were higher in every age group [10, 14]. Like prior studies, this study found high TBI rates among young males and the elderly [14]. Unlike in Victorian and nationwide data where TBI incidence rates were lowest in the 0 to 4 years age group, TBI rates in Western Australia were high in that age group [14]. Reasons for that difference are worth probing.

Comparing to international data, the hospitalised TBI incidence rate in WA of 86 per 100,000 is slightly lower than the Finnish rate of 101 and the US rate of 91–107 [17, 18]. The difference may result from the absence of TBI suicide acts in Australia. That contrasts markedly with the United States where 18,000 hospitalised and fatal firearm suicides per year involve penetrating wounds of the brain. Firearm ownership also is much lower in Australia and several types of guns are banned.

Table 5 Adjusted hazard of death subsequent to a first-time hospitalisation for a traumatic brain or spinal cord injury in Western Australia, July 2003 to June 2008

	Traumatic brain injury			Spinal cord injury		
	HR[a]	95 % CI[b]		HR[a]	95 % CI[b]	
Severity of injury						
Not skull fracture, intracranial injury, or cervical spine	Reference category					
Intracranial injury	3.11	2.22	4.36			
Skull fracture or cervical spine	1.80	1.50	2.16	1.82	0.73	4.53
Gender						
Female	Reference category					
Male	1.12	0.97	1.29	0.66	0.30	1.45
Age						
0–14 years	Reference category					
15–24 years	3.63	1.95	6.78	0.17	0.02	1.24
25–44 years	4.87	2.65	8.93	0.25	0.04	1.40
45–64 years	12.32	6.89	22.03	0.43	0.08	2.30
65+ years	69.14	39.77	120.18	3.23	0.70	14.81
Socio-economic status						
Least disadvantage	Reference category					
Less disadvantage	0.83	0.67	1.02	1.59	0.42	5.96
Moderate disadvantage	1.00	0.80	1.24	1.44	0.40	5.19
High disadvantage	0.86	0.69	1.08	1.79	0.56	5.73
Extreme disadvantage	0.91	0.73	1.13	1.06	0.30	3.68
Location						
Metro	Reference category					
Rural	0.79	0.64	0.97	0.45	0.09	2.16
Remote	0.85	0.61	1.18	2.24	0.66	7.59
Cause of injury						
Road crash	Reference category					
Fall	1.25	1.02	1.54	0.68	0.26	1.74
Other	1.05	0.80	1.38	2.37	0.98	5.72
Assault	2.17	1.16	4.04			

[a] Adjusted Hazard ratio

[b] 95 % Confidence interval

Strengths and limitations

A major strength of this analysis is its population-based longitudinal data from a large geographic area. An important limitation is the lack of a validated method of classifying TBI injuries by severity based on diagnosis information coded in the International Classification of Diseases, 10th Edition, Australian Modification. Presence of a skull fracture is not the ideal classifier. Coding accuracy also may be a concern. In particular, some spinal fractures conceivably involved cord injuries that were not coded in the hospitalisation dataset. The data include 6,290 discharges coded as spine injuries in addition to the 335 SCIs. With 335 cases, the SCI census is thin for analyses by cause and of mortality.

Because the data exclude deaths prior to admission, this paper does not provide a complete epidemiological picture. Those deaths, however, are not relevant to the issue of expanded compensation. Similarly, adjusting the survival regressions for co-morbidities, although a necessity for fully understanding TBI and SCI survival, would have been inappropriate in this paper given the intent to explore whether post-admission mortality rates differ between transport and other causes.

The excess mortality rates observed beyond 1 year after injury could be due to ongoing lifestyle factors like alcohol abuse or thrill-seeing rather than due to the original injury. That limitation underlies all extant analyses of the life table effects of TBI and SCI. Nevertheless, the survival data in this paper, while not the primary emphasis, are more representative than other recent estimates. Those estimates are not population-based. They come from cases treated at specific hospitals, generally specialty centres designed to achieve better outcomes than general hospitals.

Comparison of SMRs for TBI to prior studies

Table 6 describes and summarises the results of our study and other recent studies of long-term survival following TBI. Brooks, Harrison-Felix and Ratcliff [4–6, 12, 13, 24] include substantially overlapping populations, as do the two Baguley studies [4–6, 12, 13, 24]. The SMRs listed for year 1 and years 2–5 are based on studies showing average annual survival in those time periods. The column showing SMRs from year 2 onwards, however, is mixed. Some studies averaged post-acute SMRs for cases with just 1 year of exposure with ones with 20 to 30 years of exposure. Others looked at mortality over the same time period for all patients or used our approach of computing mortality rate by year post-injury, then averaging those rates across years. Shavelle took a different approach, working from a population of people who received service for TBI in 1988 or later including some patients who had survived with TBI for 20 years before 1988 [26, 27]. Thus its study population is not comparable to ones from other studies in Table 6.

Studies listed that are not population-based come from model rehabilitation centres or a disabilities programme that only capture cases with sequelae. Omission of the least debilitating TBIs could cause them to find larger than average SMRs. Conversely, more skilled care and better equipment could cause them to find lower SMRs. In the

Table 6 Summary of studies of post-acute SMRs following traumatic brain injury and comparison of their estimates with estimates from this study

References	Catchment area, any severity threshold	Population-based	Age range	Cases	Years of injury	Mortality data thru	SMR, year 1	SMR, years 2–5	SMR, year 2 onward
This study	Western Australia	Yes	All	8,779	7/03–6/08	2009	7.66	2.70	2.70
Baguley [5]	New South Wales	No	16-70	2,545	1990–2007	2009	12.3	4.50	2.54
Baguley [4]	New South Wales	No	All	476	1986–1996	1997			3.80
Brooks [6]	United States	No	GE 16	7,228	1988-2010	2011			2.10
Brown [7]	Olmsted County, Minnesota	Yes	All	1,448	1985–1999	2004			1.16[a]
Cameron [8]	Manitoba	Yes	18-64	1,290	1988–1991	2001	14.0	2.24	1.83[a]
Colantonio [9]	Ontario, ISS ≥12	Yes	GE 15	2,721	1993–1995	2004			2.90[a]
Harrison-Felix [13]	Denver	No	GE 16	1,678	1961–2002	2003			1.51
Harrison-Felix [12]	USA	No	GE 16	2,178	1988–2000	2001			1.95
McMillan [19]	Glasgow	No	GE 14	767	1995–1996	2003	6.33	2.27	2.32[b]
Ratcliff [24]	Pittsburgh	No	GE 14	642	1974–1984, 1988–1989	1997	4.95	2.15	2.20[a]
Selassie [25]	South Carolina	Yes	GE 15	3,679	1999–2001	15 months post-discharge	7.1[c]		
Shavelle [26]	California, cognitive deficit	No	GE 10	2,629	1960–1997	1988–97			3.10
Ventura [28]	Colorado	Yes	All	18,998	1998–2003	2005	4.95		1.71

[a] All traced for equal time periods or average of annual survival rates. Studies without this note are based on unbalanced durations

[b] SMR is 2.32 for years 2–7 and (according to McMillan et al. [20], 2.11 for years 2–13

[c] SMR is for 15 months

acute phase (1 year post-discharge), both threats to validity seem to minimally affect SMRs for TBI. Among seven studies, two of the three lowest SMRs and the second highest in year 1 were from model centres with the others from all-provider studies. Similarly, SMRs from the population-based and model centre studies of SMRs for years 2 through 5 do not differ systematically. Thus use of data from model systems does not appear to yield biased SMRs. Similarly no systematic variation was observed between all-age studies and the more numerous studies that focused on those aged 14 to 16 and older.

It appears that SMRs for TBI may be higher in year two post-discharge in Australia than elsewhere. That possibility and its cause warrant exploration.

Increase in burden if compensation is extended to all TBI and SCI

While many TBI and SCI result from road crashes in WA, a larger portion result from other injury causes that currently are not covered under compensation schemes. Extending compensation from all road crash patients to all patients with TBI and SCI would roughly triple the number of TBI patients and double the number of SCI patients covered. Table 2 showed that TBI patients in road crashes are significantly younger than patients with TBI from other causes. That means non-crash survivors will not live as long on average as crash survivors. Even controlling for age, Table 5 shows patients whose TBI is not crash related are more likely to die. Therefore, they would require less lifetime compensation than road crash patients with comparable injuries. Conversely, lifetime compensation required for SCI patients by severity is likely to match the compensation for crash survivors. Severity is similar in the transport and non-transport cohorts, so their annual costs per patient are likely to match.

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical standard This study was approved by the appropriate ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

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